Towards Regional Lunar Gravity Fields Using Lunar Prospector Extended Mission Data: Simulations and Results

S. Goossens[1], P.N.A.M. Visser[1], R.Koop[2], R. Floberghagen[3] and B.A.C. Ambrosius[1]

[1]DEOS, Faculty of Aerospace Engineering, Delft University of Technology, Netherlands
[2]SRON, Utrecht, Netherlands
[3]ESA/ESTEC, Noordwijk, Netherlands

email: sander.goossens@lr.tudelft.nl

Abstract

Until this date, the lunar gravimetric inverse problem has mainly been posed as a global problem, solving for gravity fields over the whole of the Moon. The asymmetric sampling of the force field requires that some sort of regularisation be applied in order to have a meaningful global solution that does not provide spurious information on the far side. On one hand these global solutions work very well in terms of overall orbit quality and consistency, despite the fact that roughly one half of the surface lacks sampling. On the other hand, excellently sampled regions cannot be determined at maximum spatial resolution without affecting too much the solution on the far side, which in itself is highly unstable.

Since the Lunar Prospector mission, there are many of such excellently sampled regions on the near side of the Moon. In order to exhaust the information present in the tracking data of this satellite, regional methods for solving the gravity field of well-sampled areas become interesting.

We present a method to extract regional gravity information from Doppler and Range tracking of the Lunar Prospector spacecraft. The method incorporates the GEODYN II software package for tracking data processing and orbit determination, and a software package to analyse the residuals from the orbit determination process, and to transform these residuals into gravity anomalies on the lunar surface by means of a Stokes method. Simulations will show how well a gravity signal in the residuals can be recovered. Results from orbit determination using 20 days of Lunar Prospector Extended Mission data will be shown, to demonstrate the readiness of the method to process real-life satellite data.

With missions in the future such as SELENE, which will provide the first global tracking data set of the Moon ever, global and regional methods to solve for gravity field products will remain equally of interest, since they both can give complementary insight into the low and high resolution gravity field. Regional methods can not only be used to investigate non-uniformly sampled force fields, they can also provide a localisation at higher resolution in the space domain. The method presented here can be extended to other celestial bodies of interest in planetary geodesy.

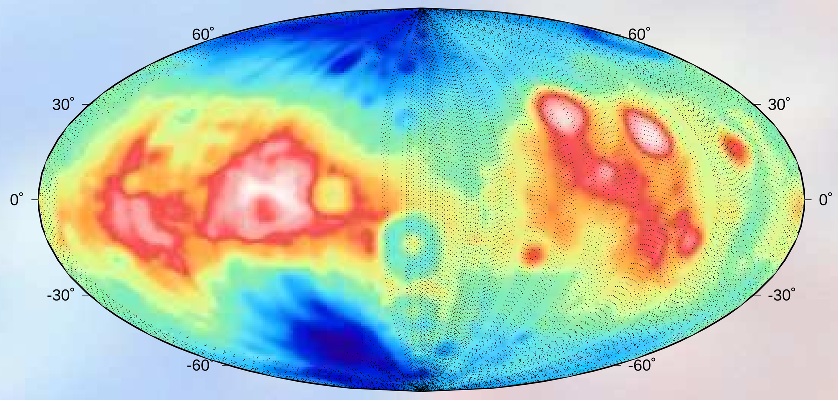
Artist's impression of Lunar Prospector, the spacecraft that in its extended mission flew at extremely low altitudes. The data from this part of the mission is used in this research, since it contains a lot of gravity information.

Acknowledgements

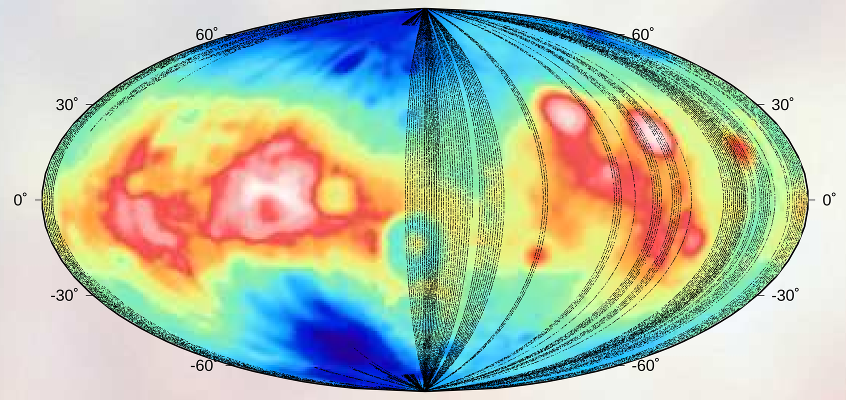
The authors would like to thank the following people for their help in preparing this work: Alex Konopliv (JPL) for providing the latest high order and degree lunar gravity model, plus a set of initial state vectors, Oliver Montenbruck (DLR) and Frank Weischede (EUMETSAT) for their help with the raw data, and Craig Markwardt (NASA/GSFC) for providing software to process the raw data.

Orbit Determination Results

Coverage range measurements



Coverage range-rate (1s) measurements



The available data (from 10 July 1999 until 31 July 1999) plotted on the lunar sphere in a Hammer projection, centered on 270° eastern longitude, leaving the far side on the left. The data is plotted on an image of the selenoid, in order to show which interesting parts are covered by the available data. Note that Mare Crisium is covered well, and that there are also some interesting tracks over Mare Serenitatis.The range-rate data is integrated Doppler data; the integration interval here is 1s, to show high resolution Doppler data coverage.

Measurement models

Observations	2-way Doppler measurements, integrated over 30 s, data weight: 1 mm/s Range measurements, data weight: 2 m Elevation cut-off: 15° Dynamical editing
Stations	DSN stations 24, 42, 46, 61 and 66. Coordinates as published.
Tidal displacement	Love model, $h_2 = 0.6090$ and $k_2 = 0.0852$ Pole tide.

Force model

Gravity	LP150Q, latest LP model including ALL LP data. Degree and order 150.
Third bodies	All planets in solar system, ephemerides DE-200
Non-conservative	Cannon-ball model solar radiation. No albedo.
Attitude maneuvers	Some at end of mission for line-up for controlled crash. Not estimated.

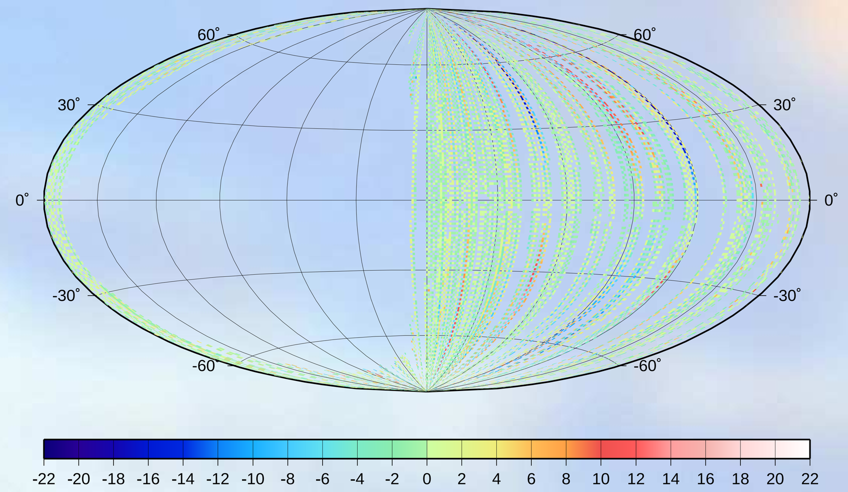
Satellite model

Mass	168.17 kg at start of data set. From published satellite ephemerides, decrease in mass is accounted for.
Cross-section	2 m^2

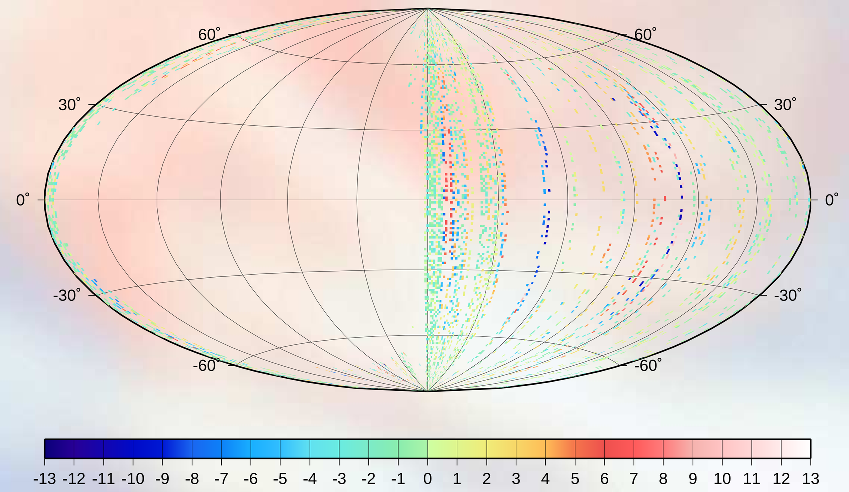
Estimation parameters

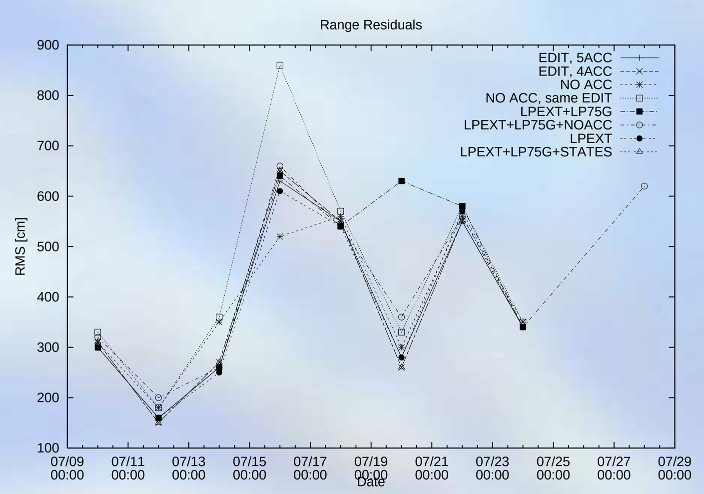
State vector	position and velocity per 2-day arc
Solar radiation	C_R coeffi cient, sigma = 0.3 or 0.001 Once per arc
Empirical accelerations	One set of 4 or 5 per 24 hours When 4: sine/cosine radial + cross When 5: idem, plus constant radial acceleration
Biases	Measurement bias for range measurements, due to range ambiguity

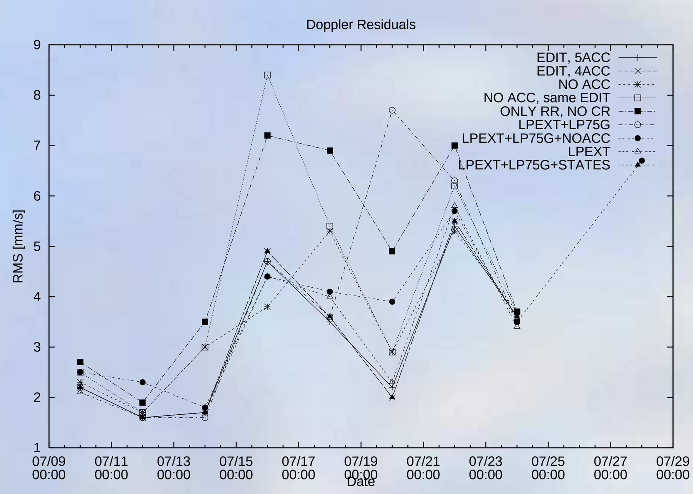
Selenographical location range residuals (m)

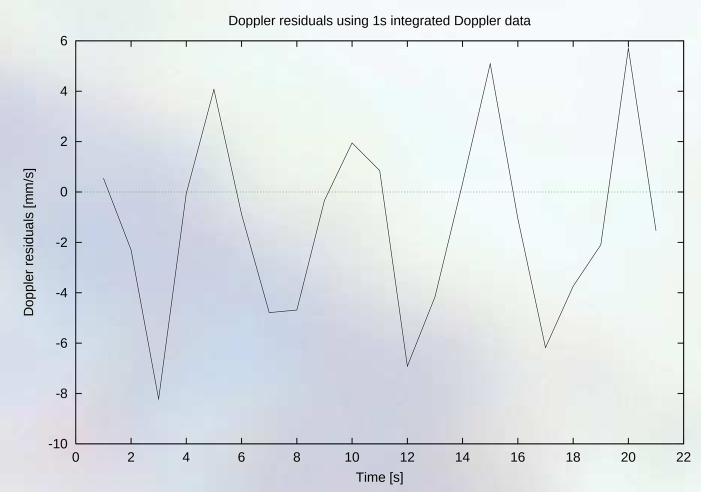


Selenographical location range-rate residuals (mm/s)









For several different test cases, using a different parametrisation, the RMS of the residuals is plotted. They all show a consistent pattern, at expected amplitude. On the right a time series of Doppler residuals using 1s integrated Doppler data is shown. This plot shows clearly the 5s spin rate of the spacecraft, which causes a bias in the Doppler data.

Gravity Anomaly Recovery

The used approach to recover regional gravity fi elds is the following:

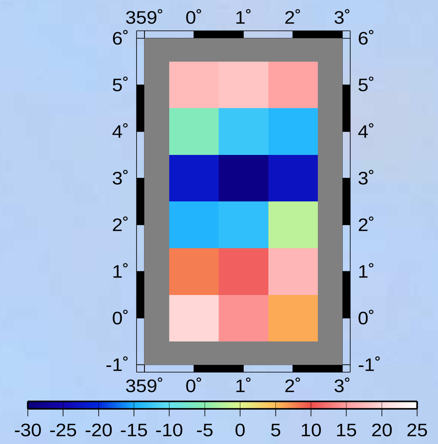
- Orbit determination on LP Extended Mission Data as described
- Analysis of residuals from OD
  - No *line-of-sight acceleration* profi les due to data gaps
  - instead: model the measurement
  - linear variational approach following *Vonbun et al., Geophys. J. R. Astr. Soc. (1980),* ***61****,645-657*

The linear variational approach consists of modelling perturbations in the measurements (range ρ and range-rate $\dot{\rho}$) as being linearly dependent on the gravity anomalies $\Delta\bar{g}$ that need to be recovered, by means of expressing them through partials:

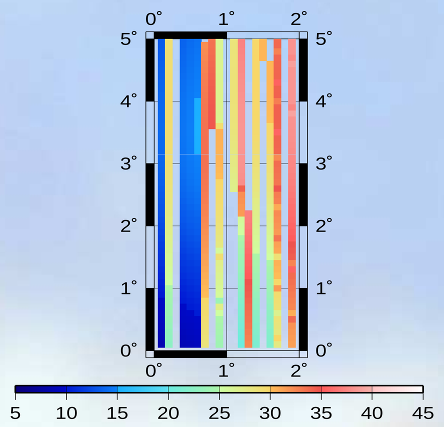
$$\Delta\rho = \frac{\partial\rho}{\partial\bar{x}} \frac{\partial\bar{x}}{\partial\Delta\bar{g}} \Delta\bar{g} + \Delta\rho^0$$
$$\Delta\dot{\rho} = \frac{\partial\dot{\rho}}{\partial\bar{x}} \frac{\partial\bar{x}}{\partial\Delta\bar{g}} \Delta\bar{g} + \Delta\dot{\rho}^0$$

Here, $\Delta\rho^0$ and $\Delta\dot{\rho}^0$ are 1 cpr signals needed to compensate for state vector effects. The partials $\frac{\partial\rho}{\partial\bar{x}}$ and $\frac{\partial\dot{\rho}}{\partial\bar{x}}$ are geometrical partials, describing the sensitivity of the range and range-rate measurements with respect to changes in the state vector. The partial $\frac{\partial\bar{x}}{\partial\Delta\bar{g}}$ is obtained by integration of the variational equations along the reference orbit, which comes out of the OD part.

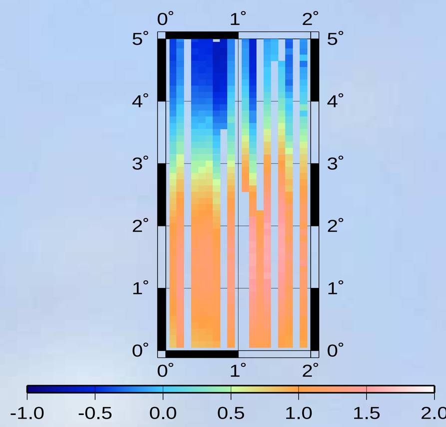
Input anomalies



Range residuals (cm)



Range-rate residuals (mm/s)



Above are input anomalies from a differenced model LP150Q-LP75G, for a 1° × 1° grid. Below that are residuals of a GEODYN orbit determination run, where an orbit without the anomalies is fitted to an orbit containing the input anomalies. Ranges and range-rates are simulated, and the residuals of those measurements are plotted for the input grid area.

Conclusions

In this research, the next step will be to focus on using the *Vonbun* method for gravity anomaly recovery. Can input anomalies from the plots above be recovered from residuals, such as shown? Points of interest are initialising the satellite tracks over the area of interest, and the influence of state vector effects.

Future efforts will include extensive simulations to test the method for its sensitivity with respect to all sorts of parameters, such as data noise, and boundary effects on the recovered area. Simultaneous simulations using GEODYN can also provide insights into the observability. After that, the method will be applied to the real LP Extended Mission Data, resulting in high resolution gravity maps for interesting areas such as Mare Crisium.

TU Delft

Delft Institute for Earth-Oriented Space Research

DEOS